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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The instrumentation and data processing techniques to apply single channel Rayleigh scattering and laser Doppler anemometry to turbulent premixed combustion has been completed. The propagation of a flame in a grid-generated turbulent and in otherwise laminar flow containing a Karman vortex street generated by a rod have been investigated. Three reports describing this work have been completed and are in the process of publication. The ratio of turbulent length scale to laminar flame thickness and the turbulent intensity predict that the

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wrinkled laminar flame model should be valid for the physical structure of the turbulent flame. The results appear to be in agreement with this model. They also indicate a reduction of turbulent intensities behind the flame and no evidence of combustion generated turbulence, b appreciable volume of intermediate states (partially burned gas) in the combustion zone, c perturbation and increase of the upstream turbulence by the turbulence flame, d interference of the rod flame-holder wake with the flame for small angles of the flame front to the flow, and e apparent disappearance of rod-generated vortices behind the flame.

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UNIVERSITY OF CALIFORNIA
DEPARTMENT OF MECHANICAL ENGINEERING
BERKELEY, CA 94720

ANNUAL REPORT
1 MAR 80-1 MAR 81

BY
L TALBOT & F ROBBEN

TO
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH/NA
BOLLING AFB, DC 20332

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RESEARCH OBJECTIVES

The overall objectives of this research are the development of diagnostic techniques for turbulent combustion based on Rayleigh scattering and laser doppler anemometry, and the application of these experimental techniques to flame propagation in turbulent flows to determine the physical structure and other properties of turbulent flames under well-characterized conditions. Five specific objectives are:

1. Application to the interaction of a Kármán vortex street with a plane flame front.
2. Application to flame front propagation in grid-induced turbulence.
3. Extension of diagnostic techniques to provide various correlations:
   a) two-point correlation of density fluctuations;
   b) cross-correlation of fluctuating velocity components;
   c) cross-correlation of density and velocity fluctuations;
   d) two-point correlation of velocity fluctuations.
4. Application of cross-correlation techniques to determine the physical structure and other properties of flames propagating in grid-generated turbulent flows.
5. Investigation of flame propagation under conditions of higher turbulence levels where the wrinkled flame model becomes inapplicable.

STATUS OF THE RESEARCH EFFORT

In this last year several of the research objectives have been met with the results contained in papers which are in the process of publication. The following statements of research progress follow the order and numbering of the Research Objectives.

1. A doctoral thesis has been completed on the interaction of a Kármán-vortex

street with a flame front. The results are based on detailed mapping of the density and the axial component of the flow velocity throughout the region of flow surrounding the rod-stabilized flame. The use of an outer co-axial air flow to reduce the flame fluctuations associated with the boundaries of the combustible flow was successful. The computerized experimental control and data acquisition system functioned as planned and made possible the extensive and complete flow field surveys, the acquisition of the data for the phase-locked measurements and subsequent analysis of discrete vortices, and the statistical analyses of the data.

The results of this research may be divided into two parts; a) the statistical analysis of the turbulent flame characteristics and comparison with theoretical models, and b) the phase-locked measurements showing the interaction of discrete vortices with the flame and comparison with the results of some unique numerical calculations.

a) The mean statistical properties of the flame show the development of the turbulent flame brush by the vortex street and the reduction in turbulent intensity behind the flame along with the disappearance of a discernable wake from the turbulence-generating rod. The probability density functions of the density indicate the general validity of a flame sheet model based on the presence of burned and unburned gas, but with significant (~ 30%) contribution of intermediate states. Detailed comparison with some of the theoretical predictions of Bray, Moss and Libby show reasonable agreement but also indicate the necessity of taking intermediate states into account in order to obtain quantitative agreement.

b) By using the phase-locked technique for recording the vortex structure it was possible to obtain complete mapping of the flow field for given positions of the Kármán vortices shed by the rod. Contour plots of constant velocity contours indicate the vortex structure. When a flame is present the vortex structure is distorted and displaced upstream of the flame front, and is not discernable downstream of the flame. The flame front is radically distorted by the vortices as is most clearly evident from the density measurements. As expected from the scale of the turbulence and the Damkohler number, it appears that there is only a single flame front which is distorted, and that pockets of burned and unburned gas are not being generated.

The experimental results were compared with numerical calculations of the flow and flame front, due to Karasalo et al. In these calculations single vortices are inserted into the flow to simulate the Kármán vortex street, and the flame is modelled as a line source of specific volume. There is qualitative agreement between the experiment and the model calculations, but the calculations indicate considerably less perturbation of the flame front than found experimentally.

Further interpretation and analysis of the experimental results is underway. A refinement of the numerical calculations which will model the vortex structure more realistically is being carried out.

2) An extensive set of measurements on turbulent flame structure in the same apparatus but in the presence of homogeneous, isotropic grid-generated turbulence has been carried out. Two-dimensional maps of axial flow velocity and density were obtained for three different flow velocities and several equivalence ratios. The results are reported in two papers which have been accepted for publication.

Several general results can be summarized. Under all conditions the turbulence intensity behind the flame is less than ahead of it, indicating that the flame does not generate turbulence, but instead reduces the turbulence level. However, large fluctuations in velocity are found within the flame front, which are not really due to turbulence as normally defined but instead due to fluctuations of the instantaneous flame front. Outside of and behind the flame front the turbulence level is reduced, as mentioned above.

A modest increase in the turbulence intensity ahead of the flame is found, which is due to the influence of the fluctuating flame on the upstream flow. This effect may be important in determining the structure and fluctuations of the flame front. For highly oblique flames, where the flow is nearly parallel to the flame front, the effect of the wake of the flame holder (a small rod) becomes important and may mask the effect of the initial level of turbulence in the flow.

The probability density functions indicate that the flame structure is approximated by a flame sheet model, but that intermediate states, lying between the fully burned and unburned gas, account for about 30% of the time history of the density in the combustion zone. Comparisons with some of the predictions of the Bray-Moss-Libby flame structure model yield qualitative agreement with an infinitesimally thin flame front model.

3) All preparations have been completed to obtain two-point correlations of density fluctuations using two-channel Rayleigh scattering, and cross correlations of density and velocity, combining Rayleigh scattering and laser Doppler velocimetry. The results of the two-point density measurements will further test the validity of a wrinkled laminar flame model for the flame structure. The density-velocity correlation will provide an important parameter for the modelling of flame structure. Measurements of the directional and spatial correlations of velocity depend upon the acquisition of equipment for a second laser doppler velocimeter channel and have been postponed.

One of the problems of Rayleigh scattering is to maximize the collection of the scattered light, thereby reducing the background noise and extending the measurements to higher frequencies. A large numerical aperture lens system (f/number of 1.0) has been designed and will be acquired.

4) The investigation of flames in grid-generated turbulence using two-point

density measurements, and combined density and velocity measurements, will begin shortly.

5) Perforated plates with high blockage ratios have been investigated and found to generate higher turbulence ratios than can be produced with grids, the objective being to obtain turbulence levels for which the wrinkled laminar flame model no longer applies. It was found that although higher turbulence intensities than those obtained in grid flows can be generated, the turbulence is no longer isotropic and homogeneous as with low-blockage-ratio grids. Inspection of schlieren photographs of rod stabilized flames in these flows indicated a more turbulent flame structure and perhaps breakdown of the wrinkled flame model.

PUBLICATIONS

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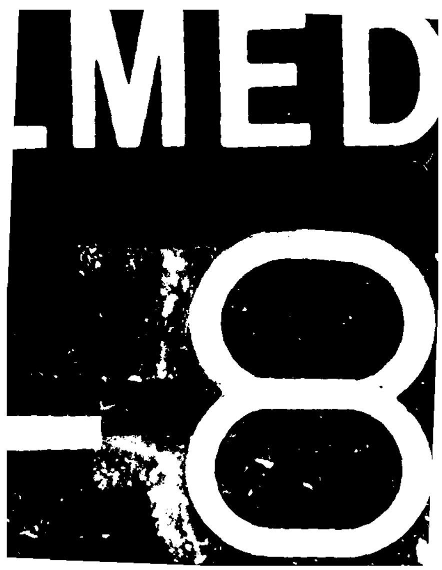
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